Medical
Research
Journal

RECONSTRUCTION OF CRANIAL VAULT BONE DEFECTS USING CAD/CAM TECHNOLOGY AT THE REHABILITATION STAGE: A LITERATURE REVIEW

Komron Saidov
Samarkand State Medical University, Samarqand, Uzbekistan

Abstract. The number of victims with post-traumatic and post-trepanation defects of the cranial vault bones who require restoration of the integrity of the skull is growing annually. The trend is due to the increase in the number of severe craniocerebral injuries, as well as the expansion of indications for decompressive cranial trepanation, in particular in craniocerebral trauma, vascular pathology, neurooncology for the purpose of stopping hypertension. sion -dislocation syndrome. Carrying out cranioplasty at the stage of early rehabilitation of patients after decompressive craniotomy is an important condition for the effectiveness of rehabilitation measures. Currently, titanium, polyether ether ketone (PEEK), polymethyl methacrylate (PMMA) and hydroxyapatite are actively used as implant materials . Unfortunately, none of the synthetic materials used meets the conditions of the "ideal implant" by 100%. To achieve absolute accuracy of the implant, repeating the missing part of the patient's skull bone, CAD / CAM 3D printing technologies are used, which is especially important in the presence of extensive and complex defects. The use of computer capabilities at the preoperative stage directly in the medical institution where cranioplasty will be performed allows you to avoid additional logistics, reduce the time from the patient's admission to the hospital until the operation and reduce the cost of implant production, making them more accessible to healthcare institutions. The absence of the need for intraoperative adjustment of the implant also significantly reduces the time of the operation, reduces the risk of infectious complications and complications associated with prolonged general anesthesia. The favorable course of the postoperative period allows for the resumption of rehabilitation measures on the 3rd-4th day after cranioplasty .
Keywords: 3D technology; cranioplasty; rehabilitation; skull defects

Аннотация. Количество пострадавших с посттравматическими и посттрепанационными дефектами костей свода черепа, которым необходимо восстановление целостности черепа, ежегодно растет. Тенденция обусловлена ростом числа тяжелых черепно-мозговых травм, также расширением показаний к декомпрессивной трепанации черепа, в частности при черепно-мозговой травме, сосудистой патологии, нейроонкологии с целью купирования гипертен зионно-дислокационного синдрома. Проведение краниопластики на этапе ранней реабилитации пациентам после декомпрессивной трепанации черепа является важным условием эффективности реабилитационных мероприятий. В настоящее время в качестве материала для имплантата активно используются титан, полиэфир эфиркетон (PEEK), полиметилметакрилат (PMMA) и гидроксиапатит. К сожалению, ни один из применяемых синтетических материалов не отвечает условиям «идеального имплантата» на 100%. Для достижения абсолютной точности имплантата, повторяющего отсутствующую часть кости черепа пациента, применяются CAD/CAM-технологии 3D-печати, что особенно актуально

при наличии обширных и сложных дефектов. Использование компьютерных возможностей на дооперационном этапе непосредственно в медицинском учреждении, где будет проводиться краниопластика, позволяет избежать дополнительной логистики, сократить время от поступления пациента в стационар до операции и уменьшить расходы на производство имплантатов, сделав их более доступными для учреждений здравоохранения. Отсутствие необходимости интраоперационной подгонки имплантата также существенно сокращает время операции, уменьшает риск инфекционных осложнений и осложнений, связанных с длительной общей анестезией. Благоприятное течение послеоперационного периода позволяет возобновить реабилитационные мероприятия на 3–4-е сутки после краниопластики.

Ключевые слова: 3D-технология; краниопластика; реабилитация; дефекты черепа

Annotatsiya. Bosh suyagi suyaklarining shikastlanishdan keyingi va trepanatsiyadan keyingi nuqsonlari bo'lgan bemorlarning soni har yili bosh suyagining yaxlitligini tiklashni talab qiladi. Ushbu tendentsiya og'ir kranioserebral shikastlanishlar sonining ko'payishi, shuningdek, dekompressiv kraniektomiya, xususan, gipertenziya-dislokatsiya sindromini to'xtatish maqsadida kraniokerebral travma, qon tomir patologiyasi, neyroonkologiya uchun ko'rsatmalarning kengayishi bilan bog'liq. Dekompressiv kranioplastikadan so'ng bemorlarni erta reabilitatsiya qilish bosqichida kranioplastikani o'tkazish reabilitatsiya tadbirlari samaradorligining muhim shartidir. Hozirgi vaqtda implant materiallari sifatida titan, polieter eter keton (PEEK), polimetil metakrilat (PMMA) va gidroksiapatit faol qo'llaniladi. Afsuski, ishlatiladigan sintetik materiallarning hech biri "ideal implant" shartlariga 100% javob bermaydi. Bemorning bosh suyagining etishmayotgan qismini takrorlash uchun implantning mutlaq aniqligiga erishish uchun CAD/CAM 3D bosib chiqarish texnologiyalari qo'llaniladi, bu ayniqsa keng va murakkab nuqsonlar mavjud bo'lganda muhimdir. Operatsiyadan oldingi bosqichda kompyuter imkoniyatlaridan to'g'ridan-to'g'ri kranioplastika o'tkaziladigan tibbiyot muassasasida foydalanish qo'shimcha moddiy-texnik vositalardan qochish, bemorni kasalxonaga yotqizishdan to operatsiyagacha bo'lgan vaqtni qisqartirish va implantlarni ishlab chiqarish xarajatlarini kamaytirish, ularni sog'liqni saqlash muassasalari uchun qulayroq qilish imkonini beradi. Implantatsiyani intraoperativ o'rnatish zarurati yo'qligi, shuningdek, operatsiya vaqtini sezilarli darajada qisqartiradi, yuqumli asoratlar va uzoq muddatli umumiy behushlik bilan bog'liq asoratlar xavfini kamaytiradi. Operatsiyadan keyingi davrning qulay kursi kranioplastikadan keyingi 3-4-kuni reabilitatsiya tadbirlarini tiklashga imkon beradi.

Kalit so'zlar: 3D texnologiyasi; kranioplastika; reabilitatsiya; bosh suyagi defektlari

Introduction. The number of victims with post-traumatic and post-trepanation defects of the cranial vault bones who require restoration of the integrity of the skull is growing annually, which is due to the increase in the number of severe craniocerebral injuries, as well as the expansion of indications for decompressive cranial trepanation associated with craniocerebral trauma, vascular pathology, neurooncology for the relief of hypertension -dislocation syndrome (Fig. 1) [1–3]. Subsequently, when the condition stabilizes and the risk of brain tissue wedging disappears, the presence of defects in the cranial vault bones causes “trepanned skull syndrome” in patients, which includes headaches, including those associated with changes in environmental conditions, neurosis-like and depressive disorders, cosmetic defects in the form of a sunken skin flap in the area of the defect, as well as protrusion of intracranial contents into the trepanation window during physical exertion, coughing, sneezing, etc. Such patients need restoration of the integrity of the skull not only for cosmetic but also for therapeutic purposes [2, 4].

Modern studies on this topic have shown that cranioplasty after decompressive craniotomy can improve the patient's neurological status, especially if performed early after decompressive craniotomy, which is of great importance for further rehabilitation and its timing [5, 6]. Currently, the optimal time for performing plastic surgery of cranial vault bone defects is considered to be an interval from 1 to 6 months after decompressive craniotomy [1, 4]. Despite the apparent simplicity of this operation, cranioplasty remains a rather labor-intensive and painstaking procedure for maxillofacial and neurosurgeons, associated with a potential risk of complications [7–9].

Selection of implant material. Another topic actively discussed in modern scientific literature is the choice of implant material for cranioplasty . Plastic surgery of cranial bone defects is possible with auto- , allo- or xenoimplants [4, 7].

The use of alloimplants for these purposes has now been discontinued, due to the higher number of postoperative complications (resorption, risk of rejection, risk of infectious infections, including human immunodeficiency virus, hepatitis, etc.) than with other types of implantation, as well as ethical issues (use of skull bones of deceased people).

Autologous bone is still used for cranioplasty . However, the results of a number of studies show that, compared to synthetic materials, sterilized autologous bone has the highest percentage of purulent-septic complications after surgery. When plastic surgery of cranial bone defects is performed with autologous bone, there is also a risk of postoperative partial or complete resorption of the bone implant (with a probability of 25 to 50%). This is due to the fact that the body begins to perceive sterilized autologous bone as foreign and, through an aseptic inflammation reaction, “dissolves” it [2, 7, 10]. Taking into account the above-mentioned shortcomings, as well as the fact that it is not always possible to preserve autogenous bone after decompressive craniotomy or craniocerebral trauma with comminuted skull fractures, with the development of reconstructive surgery for the consequences of craniocerebral trauma, synthetic materials, so-called xenografts , have been developed and introduced into clinical practice for cranioplasty .

For xenografts used in cranioplasty at present, there are a number of requirements that define the “ideal” material. The implant must be strong enough to perform a protective function with respect to the intracranial contents; it must be absolutely biologically inert, precisely repeat the shape of the missing part of the skull bones, and also not cause purulent-septic complications or rejection reactions after surgery [1, 11]. Unfortunately, none of the synthetic materials currently used meets these conditions 100% [1, 7, 11].

Historically, absolutely different synthetic materials have been used for cranioplasty , most of which, for objective reasons, are not currently used. Thus, the first metal successfully used in the plastic surgery of cranial bone defects was aluminum (Booth and Curtis , 1893). In various historical periods, steel, gold, silver, and tantalum were also used for these purposes, but they had their own significant drawbacks and are not currently used. Of the synthetic materials for cranioplasty, titanium, polyether ether ketone (polyether ether ketone , PEEK), polymethyl methacrylate (poly (methyl methacrylate , PMMA) and hydroxyapatite [12–14].

Xenografts made of titanium. Two types of material are used. The first is a titanium mesh (Fig. 2), from which the implant is formed in the factory or in the operating room. The titanium mesh is flexible and can be formed manually. Accordingly, under certain physical influences, implants made of such material are deformed, which may require revision or replacement. The second option is factory-made titanium implants. Such products are durable, but their Intraoperative adjustment in

case of mismatch with the edges of the defect is difficult and time-consuming. The manufacture of such implants is possible using 3D printing technology when fusing titanium powder. In this case, by-products may form, the absolute safety of which for the patient's body has not been proven . Other problems with titanium implants , in addition to their high cost, include a decrease in the quality of life of patients: for example, if a person loses the certificate of their installation, the possibilities for general diagnostics are limited, including magnetic resonance imaging, in addition, a titanium implant gives a positive signal on all metal detection systems , which creates additional inconvenience when moving the patient [11, 13, 14].

Hydroxyapatite is a natural material, one of the components of bone tissue. The only xenograft that is eventually replaced by bone tissue. Its disadvantages include high cost, fragility before replacement by bone tissue, and the need for only factory-made implants . Polyetheretherketone (PEEK) is a high-temperature plastic, quite durable and biologically inert - it is currently successfully used for the production of implants in neurosurgery (including spinal), orthopedics and dentistry. The only material option to date, certified for the production of medical implants, which is quite expensive, since it is produced abroad, is PEEK OPTIMA [15].

Selecting a method for modeling an implant The greatest difficulties in restoring the normal contours and configuration of the cranial vault arise in cases of large defects and/or complex shapes. In this regard, not only the choice of plastic material, but also the method of modeling the implant plays a major role. Modeling implants during surgery narrows the choice of plastic material, reduces the predictability of the cosmetic result, while increasing the duration of surgical intervention. In recent years, modern computer technologies for the production of individual implants have been introduced into medical practice in order to eliminate skull defects based on spiral computed tomography data (see Fig. 1). They make it possible to manufacture an implant from virtually any synthetic material using a direct or indirect method [15]. In the case of indirect manufacturing, an implant design is first created using a computer modeling method (computer aided designe , CAD). Then, its template is made using the rapid prototyping method [16]. An example is the method of producing stereolithographic models of a patient's skull with a bone defect area and a mold for making PMMA implants (Fig. 4). An individual PMMA implant is prepared manually using a mold, which can affect its accuracy and requires a certain amount of experience on the part of the surgeon [11, 15]. The method provides for the possibility of refining the implant on sterile models and adjusting them to the edges of the defect using high-speed cutters.

More advanced is the direct industrial production of individual implants from titanium , polymeric materials, ceramics using various production technologies: high-speed milling, selective laser sintering, casting on high-precision machines equipped with a computer control system (computer aided manufacturing , CAM) [6, 15]. All of the above-mentioned implant manufacturing technologies require certain logistics, since the production of models and the products themselves is carried out outside the medical institution where the plastic surgery of the skull bone defect will be performed. And, as is known, any logistics implies the costs of time and resources , which affects the timing of the operation and the final cost of the implant.

3D printing technology also refers to CAD/CAM technologies (Fig. 5). 3D printing is a manufacturing technology that uses a special device (3D printer) to lay down layers of material (such as metal or plastic) that are fused together under high temperature to form a solid three-dimensional object. The use of 3D printing technology in medicine began with the diagnosis of diseases and educational models for training. Currently, 3D printing technology is also the

development and production of medical devices and surgical implants. In medicine, 3D printing may have a significant impact on how patients are treated for various diseases in the near future. This innovative technology is currently used for 3D printing of bones, ears, exoskeletons , air ducts, corneas, and blood vessels [17, 18].

The use of 3D printing technology for the production of cranial vault bone implants at the preoperative stage directly in the medical institution where cranioplasty will be performed will avoid additional logistics, reduce the time from the patient's admission to the hospital until the operation, reduce the operating time and reduce the cost of implant production, making them more accessible to healthcare institutions. The use of CAD/CAM 3D printing technologies in cranioplasty allows for absolute precision of the implant produced, repeating the missing part of the patient's cranial bone (Fig. 6), as a result of which the need for the stage of intraoperative adjustment of the implant to the defect disappears, which reduces the time of the operation and reduces the risk of infectious complications and complications associated with prolonged general anesthesia.

All relative contraindications are general contraindications to elective surgery, mainly associated with the presence of an acute or chronic infectious process in the patient or changes in laboratory parameters that require correction [19, 20]. The choice of material for cranioplasty and the method of manufacturing the implant is individual in each case and depends on many factors. It is preferable to use implants made of materials certified for implantation, manufactured using CAD/CAM technology [11, 15, 19].

The operation is performed under general anesthesia. Preoperative preparation is performed according to the standard technique before a planned operation. If the patient is receiving anticoagulants, they should be temporarily discontinued 24 hours before the operation. If the patient is receiving warfarin or other anticoagulants that cannot be temporarily discontinued, then for the duration of the operation and postoperative period he is transferred to low-molecular heparins in a prophylactic dosage. The skin incision should be large enough to isolate the edges of the cranial vault bone defect along its entire length. During decompressive craniotomy at the previous stage of treatment, it is important to perform expansion plasty of the dura mater, rather than simply opening or excising it, since during separation of the skin-aponeurotic flap in the area of the cranial vault bone defect, separation of the cicatricially altered brain tissue is quite traumatic and is associated with a high risk of bleeding and the formation of postoperative intracerebral hematomas. In cases where part of the dura mater in the defect area is missing, or during the isolation of the cutaneous-aponeurotic flap it is damaged and cerebrospinal fluid leaks into the wound, the next step is to perform dura mater plasty in order to seal it and prevent postoperative wound liquorrhea . The next step, when the defect of the cranial vault bones is isolated along its entire length, is to install an implant manufactured using CAD/ CAM technology on the defect and fix it to the edges of the bone defect with titanium screws with/without titanium mini-plates. The implant should be tightly attached to the cranial vault bones to avoid its further dislocation when external forces act on this area [11, 19]. It should be noted that it is important to perform careful hemostasis at all stages of the operation to prevent the formation of a hematoma in the implant area after the operation. At the end of the operation, a subcutaneous wound drainage is placed over the implant with an active aspiration system to remove residual blood and exudate from the wound in the postoperative period. In case of a favorable course of the postoperative period, the wound drainage is removed at the end of the first day after the operation. The choice of the drug and the duration of perioperative antibiotic prophylaxis are regulated by the federal clinical guidelines of the National Association for the

Control of Infections Associated with Health Care, "Principles of Organization of Perioperative Antibiotic Prophylaxis in Healthcare Institutions" (2014) [21]. In the postoperative period, the patient also receives symptomatic therapy and analgesia. If it is necessary to prescribe anticoagulants after surgery, this is possible no earlier than the third day of the postoperative period. Rehabilitation measures can also be resumed in full no earlier than the third day after the operation, provided that the postoperative period is favorable [1, 22].

Conclusion. Carrying out cranioplasty at the stage of early rehabilitation of patients after decompressive craniotomy is an important condition for the effective implementation of rehabilitation measures. Currently, titanium, polyetheretherketone (PEEK), polymethylmethacrylate (PMMA) and hydroxyapatite are actively used as implant materials . Unfortunately , none of the synthetic materials used meets the conditions of the "ideal implant" by 100%. To achieve absolute accuracy of the implant, repeating the missing part of the patient's skull bone, CAD / CAM 3D printing technologies are used, which is especially important in the presence of extensive and complex defects. The use of this technology at the preoperative stage directly in the medical institution where cranioplasty will be performed allows you to avoid additional logistics, reduce the time from the patient's admission to the hospital until the operation and reduce the cost of implant production, making them more accessible to healthcare institutions. The absence of the need for intraoperative adjustment of the implant significantly reduces the time of the operation, reduces the risk of infectious complications and complications associated with prolonged general anesthesia. The favorable course of the postoperative period allows for the resumption of rehabilitation measures on the 3rd -4th day after cranioplasty .

References:

1. Abduvoyitov, B. (2025). FARMAKOREZISTENT EPILEPSIYA BILAN OG'RIGAN BEMORLARNING JARROHLIK DAVOLASH NATIJALARI VA QONIQARSIZ JARROHLIK NATIJALARINI BASHORAT QILUVCHI OMILLAR. Modern Science and Research, 4(2), 91-92.
2. Abduvoyitov, B. (2025). POLIMIKROGIRIYALI FARMAKOREZISTENT EPILEPSIYANI DAVOLASH NATIJALARI. Modern Science and Research, 4(2), 117-121.
3. Abduvoyitov, B. (2025). FARMAKOREZISTENT EPILEPSIYADA STEROIDLARNING AHAMIYATI. Medical Research Journal, 1(1), 244-250.
4. Abduvoyitov, B. (2025). MRT ASOSIDA FARMAKO REZITENT EPILEPSIYANI TASHXISLASH VA NATIJALARNI PROGNOZ QILISH: ZAMONAVIY YONDASHUVLAR. Medical Research Journal, 1(1), 215-219.
5. Мамадалиев, А. М., Алиев, М. А., Абдувойитов, Б. Б. У., Хайритдинов, Б. Б., Фарухова, М. Ф., Гаппарова, О. И., ... & Бурхонов, А. Ш. (2022). Клинический случай риносинусогенного абсцесса головного мозга и обзор литературы. Uzbek journal of case reports, 2(2), 7-11.
6. Bahodirovich A. B. et al. Approaches to intestinal decompression during different appendicular peritonitis in children //Достижения науки и образования. – 2018. – №. 18 (40). – С. 92-95.
7. Djalolov D. A. et al. Features of microflora in the etiological structure of diffuse appendicular peritonitis //Вопросы науки и образования. – 2018. – Т. 8. – №. 2. – С. 116.
8. Abduvoyitov Bobur Bahodirovich, Djalolov Davlatshokh Abduvokhidovich, Khasanov Aziz Batirovich, Abbasov Khojimuhammad Khabibullayevich The effect of ozone on the course and

development of complications of peritonitis in children // Вопросы науки и образования. 2018. №29 (41).
9. Abduvoyitov B. B. et al. The effect of ozone on the course and development of complications of peritonitis in children //Вопросы науки и образования. – 2018. – Т. 29. – С. 110-113.
10. Bahodirovich A. B. et al. Immunological feature of the body in children with diffused appendicular peritonitis //Вопросы науки и образования. – 2019. – №. 2 (45). – С. 115-122.
11. Khader BA, Towler MR. Materials and techniques used in cranioplasty fi xation: A review. Mater Sci Eng C Mater Biol Appl. 2016;66:315–322. doi: 10.1016/j.msec.2016.04.101
12. Zanotti B, Zingaretti N, Verlicchi A, et al. Cranioplasty: Review of Materials. J Craniofac Surg. 2016;27(8): 2061–2072. doi: 10.1097/SCS.0000000000003025
13. Alkhaibary A, Alharbi A, Alnefaie N, et al. Cranioplasty: a comprehensive review of the history, materials, surgical aspects and complications. World Neurosurgery. 2020;139: 445–452. doi: 10.1016/j.wneu.2020.04.211
14. Honeybul S, Morrison DA, Ho KM, et al. A randomised controlled trial comparing autologous cranioplasty with custom-made titanium cranioplasty: long-term followup. Acta Neurochir (Wien). 2018;160(5):885–891. doi: 10.1007/s00701-018-3514-z
15. Еолчиян С.А. Пластика сложных дефектов черепа имплантатами из титана и полиэтерэтеркетона (PEEK), изготовленными по CAD/CAM технологиям // Воп росы нейрохирургии им. Н.Н. Бурденко. 2014. Т. 78, № 4. С. 3–13. [Yeolchiyan SA. Complex skull defects reconstruction with CAD/CAM titanium and polyetheretherketone (PEEK) implants. Burdenko's journal of neurosurgery. 2014;78(4):3–13. (In Russ).]
16. Cheng AC, Wee AG. Reconstruction of cranial bone defects using alloplastic implants produced from a stereolithographically-generated cranial model. Ann Acad Med Singap. 1999;28(5):692–696.
17. Ghai S, Sharma Y, Jain N, et al. Use of 3D-prin ting technologies in craniomaxillofacial surgery: a review. Oral Maxillofac Surg. 2018;22(3):249–259. doi: 10.1007/s10006-018-0704-z
18. Nyberg EL, Farris AL, Hung BP, et al. 3D-Printing Technologies for Craniofacial Rehabilitation, Recon struction, and Regeneration. Ann Biomed Eng. 2017;45(1): 45–57. doi: 10.1007/s10439-016-1668-5
19. Winn HR. Youmans Neurological Surgery. Sixth Edition. Saunders, Philadelphia; 2011. 505 p.
20. Prabhakar H, Zulfi qar A, eds. Textbook of Neuroanesthesia and Neurocritical Care. Vol. I: Neuroanesthesia. Springer Nature; 2019. doi: 10.1007/978-981-13-3387-3
21. Gopalakrishnan MS, Shanbhag NC, Shukla DP, et al. Complications of Decompressive Craniectomy. Front Neurol. 2018;9:977. doi: 10.3389/fneur.2018.00977
22. Greenberg MS. Handbook of neurosurgery. Fift h edition. Th ieme medical publishers, New York; 2001.